Historical Analogues as Anchoring References in Popular Perceptions of Spaceflight Risk

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Contribution to "Anchoring and Black Swans: Reconsidering Risk Aversion and the Future of Commercial Space", NASA Contract #NX15AC03G – Document #5

Commercial Aviation and Early Commercial Space Transportation Analogues

Introduction: Early Commercial Aviation and Commercial Space — uses and limitations of comparison. Although a popular trope holds that America is a young country and looks forward, while Europe is an old part of the world that remains focused on the past, Americans in fact lean heavily on various popular narratives of history to make sense of the present, while political contention over various interpretations of these narratives remain hot-button issues long after they have faded from direct memory.

This has similarly been true of popular thinking and discussion about space travel and exploration. The discovery and settlement of the Americas was used as an interpretive metaphor for spaceflight and prospective extraplanetary colonization almost immediately upon the publication of the first speculative scientific and engineering literature outlining its possibility. Popular entertainment in the form of pulp science fiction quickly adapted themes from Western pulp fiction to extraplanetary locations.

Thus, the analogy between space exploration and settlement and the Western discovery and colonization of the world was firmly established even in the infancy of aviation. The development of aviation with its substantial levels of risk and loss of life took place in parallel with the popularization of a literature of space exploration that assumed a similar if not greater level of risk. These attitudes took root while a parallel highly visible and highly risky activity, polar exploration, also dominated public consciousness. It was therefore natural that public attitudes toward eventual spaceflight risk began to be colored by expectations of risk drawn from the headline-dominating high-risk activities of the day.

To be fair, aviation and polar deaths loomed large partly because of their novel and exotic nature, and the fact that many of the participants in those fields were flamboyant publicity seekers and self-promoters. Pioneering aviation was a generally risky activity, over a 1,000 deaths were recorded in the years prior to 1914**. (1)** Polar deaths were fewer, but similarly attracted public attention and helped anchor expectations.

Because the overlap of the time periods of the emergence of commercial aviation and what we might call the prehistory of space flight — the speculative period in advance of publicly visible steps toward practical human spaceflight — attitudes about risk in aviation colored and anchored public expectations to an unusually large extent. A LexisNexis search performed as part of this project's research showed that almost every referenced popular press article on the fatal Virgin Galactic test flight of 31 October 2014 referenced early aviation losses as a risk comparison, almost always as an argument in favor of pressing forward with development efforts. (See Appendix A) Therefore, the following section examines in detail the precedents set by the aviation experiences and discusses its impact on anchoring public attitudes about space-flight safety.

I. Commercial Aviation.

1. Background.

Any discussion of risk perceptions in the early period of aviation must be informed by the higher general levels of risk of life, both from illness and accident, in the preceding half century, and at the same time the general public awareness that risk was rapidly falling as a result of scientific and technological progress. Everyday life had held a substantial amount of danger, and people had little choice but to accept a much higher risk of death than experienced today. At the same time improvements in safety were dramatic. For example, advances in the 1880-1910 time frame and the consequent rapid improvement in railway safety in that period turned train travel from a dangerous adventure to an activity literally as safe as remaining at home, within the space of thirty years. (2)

The twin effects of this rapid change in safety levels in travel and life in general was to still accept some level of risk in daily life, because it still seemed to be part of life in general, while creating positive attitudes toward technological progress. Risk in pushing technological frontiers was acceptable precisely because it was expected that risk-taking pioneers would lead to further progress and subsequent risk reduction.

Popular culture figures, both fictional and in public life, were often seen in aviation and polar exploration roles. Sir Ernest Shackleton's probably apocryphal advertisement for members of the *Endurance* expedition, which supposedly promised "Safe Return Doubtful", became legendary as an example of British attitudes toward risk, and was cited with admiration widely in America as well.

Thus popular culture in the US, Britain, and elsewhere in the developed world promoted an expectation of constantly improving speed, convenience, and safety in everyday life combined with an active pioneering element whose acceptance of risk was instrumental in expanding the envelope of civilization. The two poles of risk existed in a continuum with an indefinite boundary zone between them. Commercial aviation arose in that boundary zone.

Early commercial aeronautics had its roots in exhibition and adventure ballooning in the 19th Century. Almost contemporaneously with the initial pioneering period of ballooning (roughly 1783-1800), balloon exhibition flying and passenger adventure flights began to be performed by early aeronautics pioneers. In fact it is difficult to discern precisely when early pioneers began to charge for taking riders along on pioneering flights, and balloon exhibition flights became both public events in and of themselves, and adjuncts to fairs and other public gatherings by the early 19th century.

Balloons were used sporadically for military purposes, primarily observation, in the wars of the French Revolution, and became a regular part of military activity in the American Civil War. The Union army used balloons operated by civilian aeronauts as did the Confederates.

Balloon flight was regarded as hazardous prima facie. The primary legal question was that of trespass. The general resolution of the trespass issue was to consider the balloonists innocent of trespass under common law and viable only for direct damages upon landing. Balloon barnstorming liability issues were relatively trivial. However, the fact that they had become settled law by 1903 meant that with the advent of heavier-than-air aviation, these precedents could be applied more or less automatically to airplane flight. The patterns of use of ballooning — military observation, barnstorming flights for exhibition, and adventure experiences — all carried over into early heavier-than-air flight, and the commercial as well as legal precedents offered useful templates.(3)

Airships or dirigibles provided a relatively brief bridge between free-balloon and heavier-than-air flight. By introducing the element of purposeful control of flying objects, they expanded the principle of innocent overflight, as it could no longer be argued that there was no intent to trespass. It was the transient nature and lack of physical interaction with the underlying property that rendered them harmless. On the other hand, while free transit within national borders was generally accepted, it was such dirigibles that established precedents of national sovereignty over airspace, as lighter-than-air craft developed the range to cross borders on a regular basis before airplanes could.

World War One proved to be a watershed event for aviation, and inevitably affected public attitudes toward risk in aviation. By training large numbers of pilots during the war, and producing large numbers of aircraft, many of which were then made available at low cost as surplus at war's end, it created the basis for a greatly-expanded amount of aviation activity, including the initial commercial airlines, and barnstorming and exhibition (stunt) flying as a popular entertainment.

Military aviation attracted public attention during the War far out of proportion to the numbers of people involved or its military significance, as it appeared to retain the archaic characteristics of individual valor and achievement that mass industrial trench warfare made difficult to sustain otherwise. "Aces" became popular heroes, and the very high casualty rates in military aviation endowed them with the air of heroism and sacrifice. Postwar flying continued to have a high accident rate, and the public acclaim of military aces colored attitudes toward flyers for years afterwards.

By 1925, the Federal government role in the emerging commercial aviation sector became dominant, as airmail contracts provided the fledgling airlines with their first predictable revenue sources. They also allowed airlines to earn revenues without placing passengers at risk, as air travel was accurately viewed as a hazardous activity.

Still, crew losses from airmail flight crashes were highly visible to the public and an initial period of contract operation was ended, with airmail flights turned over to the Army's aviation branch. Casualties immediately increased, with the Army's "mission before safety" corporate culture, born in wartime, probably a factor. Herbert Hoover, then Secretary of Commerce, sought to regularize the situation. At his urging, the 1925 Kelly Act created a new contract-operated airmail system, and the parallel Air Commerce Act designated the Commerce Department as lead agency, and established the Bureau of Aeronautics, (BuAer) which in 1934 became the Bureau of Air Commerce.

The period between 1918 and 1941 saw an enormous transition in both the reality of air transportation and the public perception of its risk levels. Commercial air transportation began by flying airmail in WWI surplus aircraft with high casualty rates for pilots and others. Government controlled the aviation sector through the letting of airmail contracts. By the end of that period, established airline companies were flying passengers in relative safety in closed metal airliners although the public still perceived passenger air travel as riskier than other modes, with some justification.

The arrival of the Second World War could be regarded at the close of the pioneering era. The DC-3, the principle pre-war transport, went from hundreds of planes flying to thousands. Wartime aircraft production thus created reliable mass air transport. Many Americans got their first experience of aircraft flight in the military. By the end of the war pressurized transports, created new expectations of flight as normal activity in normal environments. The pressurized aircraft like the Constellation could fly at higher altitudes, making airsickness and altitude sickness far less common experiences in flight. The introduction of such pressurized aircraft allowed the creation of a reliable, safe, and reasonably comfortable air transport system, but one that was still too expensive to become the routine or default transportation option for ordinary middle-class Americans. (4) Although upper social classes flew regularly, most Americans only flew on special occasions. Still, highly visible aircraft accidents and the reality of higher passenger fatalities than rail transportation continued to anchor public perceptions of air travel as the riskier option. Airports in the 1950s and into the early 1960s featured vending machines that sold special one-trip air-accident life insurance policies, and it was not uncommon for infrequent travelers to update wills and seek religious counsel before undertaking air travel. (5)

2. Air Transport as Everyday Activity — Convergence of Safety Standards and Expectations.

The arrival of jet air transports in the late 1950s made global flying routine and affordable. This created higher traffic volumes which in turn made new air traffic control systems and substantially new airports necessary. Similarly, the regulatory system underwent transitions. In 1958, partly in response to a highly visible air accident due to air traffic control inadequacies, the CAA became the Federal Aviation Administration, in order to take on higher level of oversight and control. The Civil Aeronautics Board took on an economic regulatory role.

In 1966, as part of a general reorganization of the Executive Branch, the Johnson Administration created the Department of Transportation, a Cabinet department unifying all transportation-related agencies. (6) The FAA retained its organizational identity, but now came under the control of the Secretary of Transportation. As a consequence, aviation would now be under a uniform set of policies for first-party and third-party risk, consistent with other transportation modes. This loss of independence on the part of the FAA marked the end of “aviation exceptionalism” in regard to Federal policy on transport safety: formal recognition of air transport as being a like activity to other modes with like safety expectations. In this Federal policy followed evolving public expectations but also helped re-anchor expectations.

In parallel, the FAA completed the regularization of air transport regulation by the extension of certification to airports, an ongoing process that began in 1970.

3. Historical Questions in Air Transport

The experience of organized safety regulation, and the emergence of standards in ship navigation and railway operation unquestionably set precedents and expectations for air transport. For example, traditional maritime practice was to pay sailors partly in hard liquor and dispense it and consume it on the worksite. Steam railways, in contrast, quickly discovered that any consumption of alcohol during or immediately before work was incompatible with safe operation, and strict rules backed by dismissal became standard within a short period after the emergence of the occupation. Aviation began with the assumption that these rules would extend to their practice. In parallel, railway rules in this regard were extended to steam navigation as well. (7)

Consider also the emergence of the "Certificate of Airworthiness" as parallel to earlier "Certificate of Seaworthiness" in ocean navigation. One difference is that the certificate in ocean navigation began as a private, voluntary measure set and administered by the maritime insurance industry. Competing standards were issued and maintained by various bodies — standards of the London insurers, for example, were stricter than those of Liverpool in the 19th century. (8) Eventually perceptions of a "race to the bottom" between competing standards led to political pressure for a uniform standard enforced by government. By contrast, aviation, emerging in an era of increasing reliance on government regulation, saw compulsory, government-issued Certificates of Airworthiness from an early date.

The term "Air Navigation" itself assumes a parallel to sea navigation, and leads to a tendency to extend by default maritime concepts to aviation (e.g., aircraft commander as "captain"). This analogy is not illogical, particularly in regard to transoceanic flight. However, there are portions of maritime practice which stem from the situation of long voyages in which the ship is also a residence, workplace, and seagoing community that must be administered and governed, and day-to-day life must be provided for in a manner that ordinary aircraft typically do not experience. Eventually, human spaceflight will replicate such conditions and seagoing practices will probably be a useful reference point, quite possibly more so than aviation practices. (9) The question of risks unique to long-duration isolation and inaccessibility of specialized medical services for serious problems, which are more likely to emerge with longer-duration isolation, has already arisen in regard to International Space Station (ISS) standards for evacuation. Aviation, in contrast, offers few useful parallels.

Reference was made previously to the phenomenon of special air-travel life insurance policies sold in vending machines in airports during earlier eras of air transport. This suggests another aspect of the air transport analogy that may be a fruitful avenue for follow-on research. Research might be undertaken as to whether the availability of insurance policies specifically for air passenger risk, and the history of premia charge for such policies serve as a proxy or metric for social perception of risk.

A related area of research might be how public perception of risk in air transport (i.e., that borne by passengers in commercial flight, rather than test flying or exploration) evolved. Research examples might include explicit or implied attitudes in popular film and fiction of 1920s, 30s, 40s, etc., (e.g., N. Shute's novel *No Highway,* adapted for film as *No Highway In The Sky*). Similarly, it might be useful to determine when practices such as that of parents flying separately to reduce the risk of orphaning children, or company policies prohibiting key personnel from flying on same plane became uncommon. Even a cursory review suggests that such practices continued long after air transport risk fell well below private car transport risk.

It would also be useful to attempt to determine how critical the unification of the transport regulatory role in a single Cabinet department was to the convergence of safety goals and metrics across transport sectors. Such further study would attempt to determine the organizational mechanism used within DOT to derive safety goals and metrics, and to incorporate such into sector-specific metrics and regulations. Related questions include determining what the time frame was for this convergence, and to what degree convergence had been under way prior to the 1966 unification, and what, if any, organizational frameworks existed to coordinate safety standards, goals, and metrics across transport sectors? Also, it would be useful to know whether any other paths to convergence were considered and rejected?

Detailed knowledge of the "normalizing" of aviation risk expectations could be a useful precedent if it were found desirable to similarly normalize risk expectations and the quantification of a VSL across all federally supported research in high-risk environments, including space.

Similarly, it would be useful to determine the effect of sector-specific international agreements on air transport liability limits, specifically the Warsaw Convention and its successors. Such study would seek to determine whether sector-specific liability caps serve to retard convergence, advance it, or have a neutral effect. Purely domestic air transport, the bulk of US air transport activity, was exempted from the treaty, as ticket legends never failed to emphasize.

4. Preliminary Conclusions.

a. Air transport safety standards during the early and pioneering periods were heavily affected by a general public consensus on participant-borne risk, and the higher general level of lethal accidents due both to technological limitations and fatalism persisting from earlier, more dangerous times.

b. As air transport evolved technically, initial movements toward imposing safety standards naturally looked toward other examples in transportation, e.g., "Certificates of Airworthiness" on the model of maritime "Certificates of Seaworthiness". However, parallel means did not immediately lead to parallel expectations of safety, as "Air exceptionalism" continued to color expectations.

c. As air transport evolved from being an elite activity to a mass activity, public opinion shifted to expecting an implicit "zero loss" standard, in which every accident required an explanation and visible measures to prevent its recurrence, similar to expectations in other sectors of public transportation. "Air exceptionalism" has been extinguished in everyday commercial aviation.

d. Organizational unification and harmonization of regulation across sectors through creation of a Department of Transportation was coincident with a gradual convergence of risk standards and metrics across transport sectors, leading to a uniform standard of hazard for crew, passengers, and third parties alike. It is reasonable to assume that the unification of metrics and standards was a natural consequence of this organizational unification, and that convergence would have been slower, less thorough and consistent, or even nonexistent in its absence.

II. Commercial Space Transportation.

1. What is "Commercial"? What is "Space Transportation"?

Since the overall topic of this study is safety standards, the working definition for this paper will be functional. "Government" space transportation is that in which a governmental body directly controls the operational decision of a flight activity, even if the physical functions are carried out by employees of private companies. A "Commercial" space transport activity is that in which a private party directly controls the operational activity, even when a governmental customer may dictate the overall mission parameters though contractual requirements, or a governmental regulator may limit operator options through the regulatory power.

Similarly, for the purposes of this work, "Space transportation" is any carriage of persons or goods or equipment from the Earth to any location beyond the atmosphere, or between two points beyond the atmosphere, or the testing in flight of equipment designed for space transportation even if it is not beyond the Earth's atmosphere. (Thus the loss in test of SpaceShip Two on 31 October 2014 is a "space transportation accident" for the purposes of discussion of this work.) A point-to-point craft designed for transport between two locations on Earth would not be considered a "space transportation" activity even if it operated outside the Earth's atmosphere for part of its flight. "Outside the atmosphere" for the purposes of this work shall be defined as an altitude at which aerodynamic control surfaces are not sufficient to control a craft; effectively, 100,000 feet.

2. Background

Governmental space activity. Unlike the situation with commercial aviation, space transportation is heavily colored by the fact that the first thirty years of that field were dominated by government-financed and -operated space transportation systems. In turn, these governmental space transportation systems were heavily influenced by the fact that they were almost entirely derived from ballistic missiles developed as weapons of war in the late 1940s and 1950s. Thus choices were constrained by path dependence set by use of ballistic missile design assumptions that were not necessarily relevant to space transportation requirements, and in some cases inherently opposed, such as the non-reusability.

Safety practices in government space transportation were similarly bounded by inherited practices from ballistic missile testing and development, many of which in turn were derived from practices in artillery. When human crews began to be flown, safety expectations, practices, and metrics were derived from aircraft development testing practices, rather than commercial aviation routine passenger practices. Other standards evolved under the pressure of the "Space Race", in which failure, even in testing and highly risky exploration activity, represented a public relations failure that generated great pressure from the political level on civil service management; thus "space exceptionalism" and the perceived political need to avoid visible loss.

The urgency to begin human orbital spaceflight, created as a result of the successful Soviet launch of Yuri Gagarin on April 12th, 1961, led to a rush program of ballistic launch using the Mercury ballistic capsule. This led to the eclipse, and ultimate termination, of an alternate path to human spaceflight that was being pursued with steady, but less spectacular success. This was the X-15 suborbital spaceplane, which successfully demonstrated the ability to control flight above the limit of aerodynamic control, return safely, and reuse the vehicle with minimum refurbishment multiple times. This program operated as an experimental aircraft, under experimental flight rules and safety assumptions, which were much less sensitive to visible loss. A thought experiment on the possible development of spaceflight had an evolutionary path from X-15 operations been chosen might be a useful follow-on exercise.

3. Emergence of Commercial Space transportation

Prehistory of non-governmental spaceflight in the US. Initial experimentation with rockets to conduct research, or otherwise reach high altitude, in the US were not governmental, but rather conducted by hobbyists and independent private researchers. The principal example was Robert H. Goddard, who developed some of the first liquid-fueled rockets through non-governmental means. His final pre-war effort, the "J" model of 1939, included most of the features of modern liquid-fueled rockets, and was comparable to parallel work being performed in Germany and the then-USSR. Goddard conducted his test flights in a low-population-density area of New Mexico and never caused damage to persons or property, so that safety and regulation were not issues in his activity.

Private, commercial operation of space launch vehicles was occasionally discussed in literature between the initial governmental space launches and the actual advent of US commercial launch activities in 1981, but no actual efforts were conducted. The first private, commercial development of launch vehicles was attempted outside of the USA, by the German company Orbital Transport und Raketen AG (OTRAG), formed in 1975. OTRAG was shut down in 1979 under pressure from the Federal Republic of Germany, but its example served to legitimize the concept and was cited by a number of entrepreneurs in the USA and elsewhere.

The OTRAG example, although ultimately unsuccessful for a combination of business and regulatory reasons, did serve to validate the concept of private space development. Taking advantage of this validation, in 1980, US commercial space advocate Gary Hudson and Texas investor David Hannah founded a pair of companies, GCH, Inc. (owned primarily by Hudson) and Space Services, Inc. (owned primarily by Hannah and associated investors). SSI secured property at Matagorda Island, Texas, and developed a launch site for suborbital testing of the *Percheron* test article built by Hudson's company. (12)

The SSI launch activity, which was announced as scheduled for 1981, triggered the requirement of a policy and regulatory response from the US government. No existing US law or regulation had anticipated private launch activity. Yet international law, in the form of the Outer Space Treaty and its associated Liability Convention created a positive requirement for the US to oversee the activity, and created a liability on the US Government as "launching state" for any damages done to third parties on Earth or in space. The Government cobbled together an interagency process based on the FAA's requirement for airspace clearance around the launch site, and using the State Department's Office of Munitions Control (OMC) Arms Export License as the governing document. This was on the grounds that a launch vehicle is a controlled item on the OMC's Munitions List and is "exported" by being sent into space, and offshore beyond the 12-mile limit. Part of the review process for the export license was a review of third-party liabilities and a requirement that insurance adequate to indemnify the government from any Liability Convention exposures. Limits were set by a Maximum Probable Loss standard derived from aviation and maritime experience. Precedents thus set were that 1) private launch was permitted; 2) the government would only regulate for third-party liability and other treaty or statute-derived obligations; and 3) that existing Maximum Probable Loss calculation methodologies would be the departure point for third-party safety calculations. The *Percheron* exploded immediately after ignition and before liftoff on its initial test launch attempt. No personnel were injured, nor was any third-party damage experienced.

The 1984 legislation resulted in placing commercial space under the Secretary of Transportation, which resulted in the convergence of space transportation third-party risk exposures with national transportation policy.

Several other launches or launch attempts were licensed under this impromptu regime. However, its inadequacy led to a regulatory and legislative process that produced an executive determination in 1983 that the Department of Transportation would become the lead agency for space regulatory activity, and the Secretary (at that time, Elizabeth Dole) formed an office within the Office of the Secretary of Transportation, termed the Office of Commercial Space Transportation (OCST) to carry out its functions. This was followed by the original Commercial Space Launch Act (CSLA) of 1984, which largely codified the executive order of the previous year, formally assigning the regulatory lead role to the Secretary of Transportation. The Act was also significant in encoding the third-party safety standard into law, a decision that has anchored expectations on regulation since then.

The OCST approached launch site third party risk through two tracks. The CSLA also permitted the use of the Federal launch ranges by private companies on a reimbursable basis. Such users conformed to existing Federal launch range safety rules (on Air Force facilities, AFR-127-1), essentially as condition of the landlord-tenant relationship created by the use agreement. Therefore, OCST incorporated compliance with Air Force range safety and ground safety (i.e., activities on base prior to launch) as a condition of the launch license, and relied on this compliance as a safe harbor for third-party safety compliance. This was one path, and one which was used by that class of private operators consisting of government contractors who had taken over operation of the vehicles they had developed for the government, and now operated as private launch services. The other path was that of those private operators who developed new vehicles designed as commercial *ab initio*, and operated from non-Federal ranges. For these facilities, OCST reviewed and approved safety procedures separately, informed by federal range practice but not bound by their precedents.

As in the case of aviation standards, bringing space regulation under the umbrella of the Department of Transportation accelerated the convergence of third-party risk standards between space and all other Federal transportation forms. The Air Force range regulations were to some degree reactive, having been built up in reaction to actual or potential incidents over fifty years of ballistic missile and space launch tests and operational launches. DOT OCST personnel began the process of quantifying the risk and comparing third-party risk, moving away, in the process from the space exceptionalism that had been inherent in the AFR. The 1994 reorganization of government that resulted in the movement of OCST from the Office of the Secretary of Transportation to the Federal Aviation Administration did not hinder this process and may have helped accelerate it.

4. The Advent of Human Commercial Spaceflight, Flight Participant Safety, the Regulatory Moratorium, and Informed Consent Regimes.

The experience between 1984 and 2004 provided a learning period of twenty years in which a wide variety of existing and new space launch designs were launched by private operators with no third-party losses. As they were all uncrewed, flight participant safety did not enter into the matter. However, the advent of the Ansari X Prize for private human spaceflight brought flight participant safety to the foreground. The 1984 legislation had been amended several times, mostly making technical adjustments to the liability indemnification limits and provisions. The issue of flight participant safety was addressed by a new Amending act, which provided for an explicit authorization to fly human flight participants, providing for a ten-year learning period in which flight participants had to give informed consent to assuming the risk of flight, after which some form of safety regulation would be developed. SpaceShipOne flew to space twice in 2004 from the non-federal Mojave Air and Space Port, claiming the Prize and also demonstrating the provisions of the new legislation. The learning period established by the Amendments of 20004 was extended to 2025 by the “SPACR Act”, the U.S. Commercial Space Launch Competitiveness Act, Space Resource Exploration and Utilization Act of 2015 (13).

Over the past decade, a number of credible firms have been established, with substantial financial resources, intending to fly humans to either suborbital space or to orbit for profit. Although progress has been slower than initially projected, it is highly likely that several such firms will succeed in carrying flight participants to space in the near future. As of the writing of this document, no commercial flight participants have been launched by any of these companies. However, the firm Blue Origin has conducted several successful launches to space with their system but without human occupants. Additionally, NASA has created a Commercial Crew Program and has selected two commercial firms, Space Exploration Technologies, Inc. (SpaceX), and Boeing, to develop and operate human crewed capsules for transportation to and from the International Space Station. Thus issues of human safety standards for flight participants will likely rise to public consciousness, and all the factors discussed previously — anchoring of risk perception, the role of black swan events in such anchoring, and public attitudes about safety in extreme activities in general vs. "space exceptionalism" — will play major roles in shaping such discussions. The loss of a test pilot in the testing of the commercial SpaceShipTwo prototype on October 31st, 2014 has given a foretaste of such debate.

5. Tentative conclusions.

a. The US government will have multiple roles in establishing the safety regime for human commercial spaceflight in the coming period. Its regulatory role will likely become a mixture of informed consent approaches and codification of industry best practices as experience is gained through repeated flight events, including investigations of observed flight anomalies, whether or not they result in harm. At the same time, it will likely become a major customer for flight participant services, both through the commercial crew program for ISS, and through purchase of suborbital flight services for research services. Its power as a customer would allow it to impose additional requirements on service providers, and economies of scale may effectively impose such additional requirements on all customers.

b. The government's desire to avoid adverse publicity through accidental losses, which was a strong driver of safety requirements in government-run programs such as the Space Shuttle, may well continue in the purchase of commercial human flight services. Again, anchoring of public expectations could result in a continued disparity between the way the government purchases researcher transportation and accommodation in space services vs. other hazardous research environments such as underwater, or the Antarctic.

c. The loci of policy and operational decision-making in space personnel safety decisions will matter. Just as placing the authority for aviation and then for space in a unified transportation regulatory framework at DoT helped normalize third-party risk standards consistently across all modes, so might placing the decision loci for similar decisions regarding high-risk research environments in a unified framework help work toward a rational and consistent management of risk in all such types of research, across environments. Several models of such uniform decision loci will be offered, and pros and cons of each shall be discussed as a basis for future discussions.

III. Historical Analogues: High-Risk Scientific Research Environments

1. Introduction: Definitions of "High-Risk", "Scientific Research", and "Environments"

One of the central elements of scientific research is the comparative method. In a number of sciences, particularly in the geological, biological, and environmental sciences, gathering data on variants of the known and understood phenomena studied requires excursions into physical environments different from those that technological civilization normally inhabits. Since humans have inhabited almost every physical environment capable of sustaining life, the remaining environments are by definition hostile to some extent to human life, often extremely so. Although scientists typically attempt to collect data, including physical samples, by remote means in cases in which entry into the environment presents hazards to data collectors, this is often infeasible or sub-optimal compared to the actual presence of a data collector.

Therefore, many varieties of scientific research require that an investigator be subjected to extreme environments in the course of gathering data. A consequence of that exposure to extreme environments is an increased risk of injury or death. This risk has traditionally been accepted as a condition of being a researcher in a number of fields of inquiry. However, both the normal human instinct for self-preservation, and the fact that such researchers are often repositories of unique knowledge and capabilities, such that the loss thereof would substantially set back research in that field, have led to the adoption of risk-mitigation measures and strategies. These measures and strategies are intended to reduce the risks of loss of mission, injury to participants, and loss of life, while still not unduly burdening the activity in terms of either cost or compromise to mission goals.

Some such areas of scientific endeavor have had a substantial number of individuals engaged in high-risk research in particular environments over long periods of time. In the course of such research, metrics of safety have evolved, and sets of rules, procedures, and criteria have been imposed on individuals. Such limitations are often imposed either as a condition of funding, a condition of transport to or support in the research area, or both. This study will examine such rule sets for lessons learned in order to understand the range of risk/reward tradeoffs accepted in various fields of research, and compare them to the standards existing in human spaceflight, both de jure and de facto. For the purposes of this discussion, the following definitions will be used:

a. High risk. Levels of probability of injury or death higher than that permitted in the ordinary provision of services to the general civil population without specific disclosure and assumption of risks. For example, driving in a car on a normal road or highway, or flying on a regular scheduled civil aviation flight would constitute “ordinary provision”.

b. Scientific research. This is defined as participation in the systemic investigation of the physical universe for the purpose of increasing human understanding, undertaken using generally-accepted protocols of investigation including the gathering of data, organizing and presenting them according to accepted protocols of the field or discipline, and subjecting them for review, verification, and critique by recognized members of the profession or discipline.

c. Environments. The immediate physical surroundings in which the research takes place, or through which the experimenter must pass, in order to reach the place of research.

Imprecise boundary between research and sport. In actual practice, in some areas of research there is an overlap between the conduct of scientific data collection and sport and adventure activity. Scientists needing access to certain extreme environments such as mountains, caves, underwater locations, and polar terrain often use the same techniques, equipment, facilities, and support personnel as those developed by adventure and sport participants. Thus the practice of such sport and adventure activities benefits science by accelerating the development of techniques and equipment of use to researchers, and lowering the cost of equipment and facilities by enlarging the market for such. This will have parallels in space operations with the onset of “space tourism”. The principal difference in practice will be that scientific researchers, when planning and executing access to potential research areas, typically choose routes and destinations based on the research needs, whereas sport and adventure participants will be motivated by other criteria, such as setting records, maximizing the physical challenge (e.g., by choosing the more difficult route of ascent to a summit), or by the subjective quality of the experience. Sport and adventure participants may also accept limitations, such as eschewing available technologies that scientists would prefer to use if available. For example, a scientist would likely use mechanical transportation to access a high-altitude location, if available, whereas a sporting participant would choose to climb to it. However, scientists and sport/adventure participants alike tend to choose the safest possible means of achieving their goals, consistent with the decision to pursue the goal, even if the constraints assumed in defining the mission may differ.

2. Extreme geographies: Mountains, Deserts, and Remote Ocean Areas.

The first scientific discipline pursued in extreme environments was, in general, geography. Before any other science could be conducted away from the researcher's home locations, it was necessary to know that particular locations were there, to understand their basic characteristics such as terrain and climate, and to be able to fix their location accurately by a system of coordinates such as longitude and latitude. Exploring expeditions were in all pre-modern eras dangerous in the extreme, given the dependency on wind and tide in sea travel, and the lack, for most of that era, of any way of determining longitude in unknown waters. Medical techniques could not deal with most infectious diseases or dietary deficiency diseases. Therefore, loss of life was normal in any long-range exploration, and expeditions frequently did not return at all. To the extent that safety precautions were taken at all, they consisted primarily of redundancy, sending multiple ships or expeditions with many spare mounts so that loss of some could be withstood.

Progress gradually filled in the blank spaces on the map and made exploration a tool for other sciences. As explorers pushed into more and more extreme environments like the poles and high mountain regions, new technologies enabled safer exploration and systematic approaches to safety emerged.

Since the Federal government was the ultimate source of much of the research funding for these research activities in extreme environments, it began to require that sponsored research adhere to best safety practices within each field. However, although any given field's safety standards and practices makes implicit assumptions as to the cost/benefit tradeoffs, there is no standard, explicit assumption about the value of human life in scientific research in extreme environments. This has led to obvious disparities, particularly between research in outer space versus other extreme research environments such as Antarctica. In order to assess the desirability of a uniform standard across all extreme research environments, specifically in the polar, undersea, volcano/high mountain regions, existing safety regimes for researchers in these areas are assessed. In general, in contrast to the highly detailed safety precautions of NASA in regard to personnel both in space and in the ground environment, safety for other high-risk realms is far more informal and ad-hoc, a combination of an extension of normal workplace-safety and occupational health standards, and a compilation of best practices and experience-based rules of thumb rather than detailed procedures. Only in diving and other undersea activities, where there is a large experience base of commercial, military, and recreational users, is there a detailed analysis-based set of rules and standards that can be compared to space safety regulation. These may serve as a model for re-thinking the balance of participant safety and mission success as human commercial spaceflight greatly increases the number of humans other than governmental operating-agency employees experiencing the space environment.

3. Polar Regions

<u>a. High latitude land areas (northern Alaska/Canada, Greenland, Scandinavia, Russia).</u> Defined as land areas lying north of the Arctic Circle, (66 deg 45' North latitude, the southern limit of the region of completely sunless winters), the Arctic Circle differs from its southern counterpart in that it has been the normal habitat of significant human populations from the Paleolithic

Era onward, is the territory of several modern industrial nations, and is the location of several millions of the Earth's population, governed on the same basis as the non-Arctic areas of those states, and is the location of modern industrial, resource extraction, defense, transport, and research activities. Although the climactic conditions in the higher Arctic regions can be as severe as all but the worst of Antarctic conditions, and just as hazardous, there is far less special regulation of personnel than in the Antarctic, and safety is assured for most activities by the same sorts of occupational safety and health regulations that govern activities in the lower latitudes of those nations, although environment-specific modifications may apply.

Most employers, public or private, with operations in high Arctic location do have environment-specific rules, procedures, and training for their employees. Safety is governed by a combination of ordinary health and safety regulation and company policy, and although general health and safety law is based to some extent on cost-benefit analysis, it typically is based statistically on a nationwide experience base rather than an Arctic-specific regime. As Arctic practice is based on much larger numbers of inhabitants, a far wider range of activities, and a much longer history of operations, it serves as a reservoir of experience from which Antarctic operations can be extrapolated.

b. Arctic Ice Islands. Ice islands, or drift stations, are facilities consisting of buildings, ice runways, and other infrastructure placed on thick, flat icebergs, usually in Arctic waters where they drift in a circular pattern around the North Pole. Such stations were maintained by the USA and the Soviet Union, and used for both intelligence and research purposes. The Russian Federation continues to use such stations, and additionally one such station, Camp Barneo, is maintained by a Russian private company as a tourist destination. Safety is handled in a manner generally similar to Antarctic research stations. The best-known American drift station, Ice Island T-3, or "Fletcher's Ice Island" lasted about forty years after its discovery, and was occupied intermittently from the late1950s through the early 1980s. They are potentially interesting from a legal/regulatory standpoint, as they have no legal status, not being ships; nor located in territorial waters; nor, as with Antarctic stations, covered by a specific treaty. However, to date regulatory authority has not arisen as an issue, since the operating entity of such stations had in all cases controlled the means of access to the station, and its occupants are dependent on the continued cooperation of that entity.

c. Antarctica. As discussed previously, Antarctic activities largely draw on high Arctic experience, both in technological adaptation to its extreme environment, and in health and safety practices and regulation. The principal differences are the much smaller numbers of occupants of the research facilities, especially during the Antarctic winters, and the greater degree of isolation of many of the researchers. Parts of Antarctica have additional characteristics not found in the Arctic that also affect health and safety, particularly the fact that the South Pole station is situated at over 10,000 ft altitude. The extreme cold, altitude, and extreme dryness of the atmosphere at that location combine to provide particular challenges.

As with the High Arctic areas, safety regulation appears to be based primarily on existing national occupational safety and health regulation supplemented and modified by experience-based rules imposed through the grantor-grantee relationship. This is not as counterintuitive as it might seem at first glance. Although it might be expected that the unique and hazardous conditions of the Antarctic would produce the bulk of casualties among research and support staff there, in fact the five most common injuries there are also the five most common injuries in American workplaces in general. The most common injury in both cases is back strain due to improper lifting technique. Therefore, OSHA regulations (or the equivalent national regulations) with additional precautions for Antarctic-specific conditions has been a reasonable approach to date. (14) (15)

Although OSHA regulations in general attempt to perform a general cost-benefit analysis on workplace safety measures and at least in theory attempt to apply a consistent safety standard across the board, there is no indication that a systematic approach has been taken to Antarctic safety, in the sense of placing a consistent value on human life and evaluating alternative precautionary measures to such a standard. Rather, they appear to have tried to choose the most achievable level of safety and health consistent with mission resources and goals that have been fixed by other considerations. Thus, the decision to leave substantial staff at the South Pole station over the Southern Hemisphere winter, despite the inability to evacuate any such personnel no matter how urgent the need, appears to have been taken first on the value of the research thus made possible, and secondly, by the available level of resources for such activity.

US Soviet and other Antarctic explorers had episodes of medical crises which had to be dealt with primarily on-site resources. In one well-publicized case, a mid winter flight was made to drop supplies for treatment. And more recently the US has begun using specialized charter flights by a Canadian Arctic air provider. (16)

There is no evidence of a systematic evaluation of options for mitigating the risks of isolation, considering all options on a cost-effectiveness basis using a VSL figure for value of a staff member's life or the value of the unique research enabled by over-wintering. There are a number of measures that could have been taken to mitigate or reduce risks of isolation, but do not seem to have been seriously considered. To make a *reductio ad absurdum*, had the approach of the International Space Station been followed, a heated hanger might have been constructed at the South Pole base and transport aircraft, with crew, sufficient to evacuate the entire staff might have been maintained in flight-ready condition throughout the winter. Clearly, however, the US government has, in effect, used one implicit valuation for the life of an Antarctic researcher, and another for astronauts.

Cost-benefit analysis is used extensively in overall planning of Antarctic operations. The 2012 review of the US Antarctic Program's future logistic needs, for example, considers the possibility of constructing a packed snow runway at the South Pole station suitable for wheeled aircraft operations. Although this would also have implications for accessibility and thus personnel safety, the decisions seems to have been evaluated entirely on issues of cost-effective logistical support. (17)

A comparison with approaches taken in other Antarctic programs of countries with similar safety philosophies and standards, such as those of the British Antarctic Survey, suggest that such programs have chosen an essentially similar approach.

4. Undersea activity

Of all major contemporary research environments, the undersea environment is perhaps the most parallel to space. It has a heavy military component, a growing commercial component, and the approaches to safety, in terms of planning, use of preprogramming of activity, and constant monitoring of activity, are most astronaut-like. As with space, a human underwater at any significant depth is dependent on the proper functioning of his equipment for survival on a minute-by-minute basis.

The principal difference between diving and space is the several orders of magnitude of cost difference between access to the deep ocean environment and access to space. Thus, there is currently a thriving commercial field of underwater operations for both industrial purposes and recreation. Within this sphere of civil activities, scientists use commercial equipment, training, and capabilities in pursuit of a wide range of research objectives. Thus, regulatory approaches are also developed by existing civil means and then tailored to research activities, rather than developed de novo.

Regulation of civil underwater activities is carried out by normal civil agencies. The Occupational Safety and Health Administration (OSHA) of the Department of Labor has an extensive set of regulations and standards for commercial diving. The National Oceanic and Atmospheric Administration (NOAA), which carries out the bulk of directly-sponsored Federal scientific research activity, maintains an additional set of standards and procedures on top of the basic OSHA regulations. These regulations make a distinction between "working" diving and "scientific" diving, and regulate somewhat more lightly for the latter category. This is due primarily to the recognition that scientific diving normally uses simpler tools, involves working with lighter weights, and shorter duration of dives than working diving. (18)

The way in which the working/science distinction is applied suggests that although cost benefit analysis has been applied in general in development of OSHA and NOAA diving regulation, there has not been an overall attempt to use a nominal VSL for researcher life as a tool for tradeoffs in safety regulation in undersea activity. Rather, a consensus has emerged on the procedures and resources needed to undertake any given mission, and given that the mission falls within the standard parameters, and the appropriate precautions are observed, the activity can go forward without mission-specific analysis. Only if a set of parameters is exceeded does an intended activity require mission-specific review and approval. These safety constraints are assumed as part of the budget assumptions; as with other research areas examined, the assumptions behind the targeted level of safety could fairly be characterized as "as safe as possible while achieving the mission within accepted budget limits."

5. Active Volcano Research

Vulcanology, the study of volcanoes and related phenomena, can require the collection of data during active events such as eruptions and lava flows. These events are hazardous and unpredictable, and researchers are regularly injured and killed in the course of such data collection.

There is no governmental regulatory authority in any country specifically charged with promulgating rules for safety in vulcanology. The principal international scientific organization in that field, the International Association of Vulcanology and Chemistry of the Earth's Interior (IAVCEI) has noted the high casualty rate in vulcanological field work, and maintains a Sub-Committee on Safety, which has generated a set of recommendations for best practice in mitigating vulcanological field work hazards. These are more in the nature of best practices rather than a rigid set of regulations for conduct. The US National Science Foundation and other national funding authorities do not specifically enforce these recommendations but recognize them as accepted best practice in the discipline. (19)

The IAVCEI recommendations are essentially a combination of common sense and empirical experience-derived measures. There has been no systematic approach to vulcanological field safety and no attempt to apply cost-benefit analysis to trade-offs among safety measures, cost, and mission success.

6. Observations and Conclusions re Hazardous Research Environments Other Than Space

In general, other high-risk research environments are substantially concerned about safety, particularly as the managers and decision-makers in the administrative bodies for these fields tend to be drawn more exclusively from the research community itself, and thus have often experienced the hazards personally. As with military personnel or first responders, the voluntary acceptance of considered degree of risk, when unavoidable if the mission is to go forward, is part of the ethos of the profession.

In most cases, the research activity is carried forward with tools and capabilities developed in a wider field of military, commercial, industrial or recreational activities, and researchers often merely buy, lease, or borrow capabilities from entities in those sectors. As a result, most such fields of endeavor have well-established safety regulations set by military or civil authorities, and to the extent that scientific researchers have special regimes, they are typically laid on top of existing general regulatory regimes. These regimes usually are based on some level of cost-benefit analysis, but the costs and benefits are usually calculated on the basis of burden on profitability of the business as a whole, and the social and economic benefits of the business as a whole. Mission success of the research area that may use such capabilities is usually only a small part of the benefit to society of the general activity and scarcely affects the tradeoffs.

Only in areas like Antarctic research, where support of research is the primary goal of, e.g., Antarctic aviation, will special exemptions be made for activities such as ice or snow landing strips for research stations. In such circumstances operations may be permitted in conditions or circumstances not acceptable for regular passenger aviation in the USA. In many fields, the overlay of research-specific rules on top of whatever regulation already exists can amount to little more than suggestions of best practices, and there may be no enforcement mechanism at all.

Safety is thus dealt with in most cases in a much more empirical and less systematic manner than is the case with NASA astronautic activities. As noted, research-specific analysis on a cost-benefit tradeoff among cost, safety, and mission-success criteria is seldom explicitly made. The attitude in many such fields could be characterized more as “We have *x* budget, *y* mission goals, and *z* safety constraints. Let’s figure out how many mission goals can be achieved within that budget, given the known safety constraints.” Capital expenditure to overcome safety constraints is seldom an option; it is more likely than an exemption or variance to safety constraints would be sought.

Of the conclusions that can be drawn from this comparison, perhaps the most significant is the degree to which the anchoring of expectations, both within each field of research, and with the general public, regarding hazard and loss of life. As with aviation testing, polar, underwater, and volcanic research have inherent hazards that will likely never be entirely prevented or mitigated so long as humans must be present in the field.

In all of these research disciplines, researchers die from time to time. In most cases, their death is marked in the general media only briefly, and often not at all. When they do notice, there is no public clamor or outcry to make the research safer, or to stop it altogether. Occasionally, as in the 1999 incident case of Dr. Jerri Nielsen at South Pole Station, requiring an overflight for medical supplies, public attention is momentarily focused, but mostly because of the drama of the dilemma and ultimately the undertaking of a hazardous rescue flight. In the actual case, there was no public outcry for spending money to make the station less isolated. Neither was there any outcry to close the station during the winter season.

It is also worth noting the shift in risk perception from earlier periods of operation of the South Pole Station to the period in which Dr. Nielsen's crisis occurred. In the previous period, at least one midwinter overflight and air drop of supplies at the South Pole was performed routinely by Navy aircraft. Had Dr. Nielsen's crisis occurred during the previous period, the air drop would not have been perceived as an extraordinary event. Thus anchoring of expectations can shift as a result of redefining of events from normal to abnormal, and presumably vice versa.

In vulcanology, a small field, death of researchers is a periodic event. Such deaths are noted in immediate coverage, but they are little noted by the world at large, and often they tend to be overshadowed by the overall casualty figures for the event, which can run into the hundreds or thousands, particularly in developing nations. Both by the general public and in the research field itself, such deaths are accepted as a risk of the occupation. The death of scientists in volcanic events extends as far back as the death of the naturalist and geographer Pliny the Elder at the destruction of Pompeii in 79 AD. We can expect that such deaths will continue to be borne as a cost of research.

Anchoring of public expectations in human spaceflight, therefore, has had a strong effect on the approaches to safety by NASA, and we expect that these will to some extent carry over into regulation of commercial human spaceflight by the FAA. Loss of spaceflight participants by NASA in the Apollo 11 pad fire and in the loss of Shuttles *Challenger* and *Columbia* was in each case treated as a major national calamity, and elaborate, expensive, and in many cases only marginally useful measures were undertaken with the aim of improving safety.

We will discuss strategies for dealing with the anchoring issues in public perception of spaceflight safety, including lessons learned from parallel scientific research fields. One such strategy would be the creation of a uniform standard of research risk among all federally sponsored and federally operated research areas. Such a standard could possibly have the effect of re-anchoring public risk perceptions in space exploration to something closer to that in polar, undersea, and volcanic research.

IV. Recreation/Adventure Markets

In addition to the commercial transportation sphere, and the spheres of scientific research, people place themselves voluntarily in situations of assumed risk for non-monetary, non-occupational motivations, which can be broadly characterized as recreation and adventure. The regulatory arms of the US, state, and local governments typically accept high degrees of risk with the proviso that the participants be old enough to understand and willingly accept such risk, and that the providers of equipment and services for such activities clearly communicate the degree of risk participants are assuming. In many cases government authorities will work with organizations associated with such activities to insure that reasonable mitigations, when available, will be used within the overall goals of the activity. This does not always entail requiring the safest possible mode of activity; for example, mountaineers may choose to ascend a peak by a more dangerous route than others available, since the absolutely safe option is not to climb at all.

Within the world of adventurous recreations and sport carrying higher levels of risk than ordinary life, we can examine, for the purposes of studying regulatory approaches, two broad categories of activity: aviation sport, and all others. This is because in Anglo-American law, the fundamental assumption is that activity can be undertaken without specific permission of the government unless there is specific constitutional or statutory authority requiring such permission. The US government enjoys a blanket and comprehensive authority over aviation activities under the Federal Aviation Act and other statutes. Thus, regulation of aviation sport, including parachuting sports, is automatically included in such authority. In most other areas, regulation is accomplished by a variety of statutes, insurance requirements, best practices created by voluntary organizations such as sporting federations, occupational regulation (e.g., OSHA standards for commercial diving, whose rules are often adhered to in non-commercial diving activities) usage rules established by the government's landlord-tenant relationship (e.g., use rules for visitors in National Parks), etc. Few if any of these mechanisms incorporate anything comparable to a VSL analysis.

Therefore this discussion will address all recreational/sporting assumed risk activities in two sections, aviation, and all others.

<u>Aviation Assumed-risk activities.</u> There are a wide range of aviation-related sport and recreational activities all of which are at least somewhat riskier than routine commercial aviation. They are practiced by substantial numbers of people, in the millions in the USA alone, and constitute a major sporting activity. Skills such as parachuting have substantial usefulness to the military, first responders, forest-fire fighters, and other socially useful fields. Advances in techniques and equipment achieved by sport parachutists have frequently been adopted by civil and military users, and vice versa. This also is true of other areas such as light/sport aviation, which has many civil and military uses. Therefore, aviation sports can be seen as in the national interest above and beyond the provision of recreation to its practitioners.

As with most sporting activities, these aviation-related activities involve participant-borne risk higher than that assumed in everyday life. (20) The Roudebush study concluded that the fatality rate for non-commercial aviation, which includes general aviation and specialized aviation sports, had a fatality rate approximately ten times that of commercial aviation (although it is significant that the bulk of those fatalities was concentrated in pilots with fewer than 500 hours of flight time; more experienced pilots had fatality records comparable to commercial pilots). All other hazardous sports together (which for this study included motor racing as well) was slightly less hazardous than general aviation.

The voluntary assumption of risk up to and including loss of life for entirely optional activities makes the methodologies supporting regulatory decision-making more problematic than in activities which are ancillary to the conduct of ordinary life or the pursuit of an occupation or profession. Airlines exist to move large numbers of people rapidly between places, and regulators of airlines exist to insure that reasonable measures are taken to accomplish that task safely. Polar scientists pursue their research to improve our understanding of polar phenomena, and regulators strive to insure that such research is done in a reasonably safe manner consistent with doing the research at all.

<u>Assumed risk activities other than aviation.</u> When the goal of a sport is to maximize the physical and mental challenges to the participant in the pursuit of a defined goal, the regulatory consideration of minimizing death and injury by mandating the safest available means of accomplishing the goal, and banning or disincentivizing the use of more dangerous methods create an inherent tension. The canonical example is the decision of a mountaineer to ascend a mountain

using a more dangerous route than necessary precisely because it is more challenging. Regulators could ban such routes, or even demand that stairs and tunnels be built to render the climb safer. But such would be inconsistent with the nature of the sport.

ThIs tension between pragmatic pursuit of safer and more reliable access for research and other exploitation, and the quest for sporting challenge exists in other areas where sportive and research users share the same environment. In Antarctic research, the South Pole Traverse or "Antarctic Ice Highway", a defined and maintained route for surface vehicles between the coast and the South Pole station, began construction in 2002. (21) It was bitterly criticized by the record-setting sportsman Sir Ranulph Fiennes and Everest climber Sir Edmund Hilary as "ruining" Antarctica as an unspoiled preserve that would present an ongoing challenge to humans. (22)

The heavy sportive use of Everest and the high death toll among such climbers makes the access vs. challenge controversy particularly conspicuous. Sherpa guides now emplace fixed ladders and ropes for the entire climbing season, making the traverse safer but also reducing the time for the entire climb and thus increase the throughput of climbing parties, which is now the limiting factor for the total number of climbers per season.

One could as a thought experiment imagine constructing (at some enormous expense and difficulty) a cog railway to the summit of Everest with a pressurized, oxygen-supplied station, allowing the summit to be obtained in perfect safety and ease. Researchers would no doubt find many uses for such a station, and sportsmen could of course still climb the mountain the traditional way. The presence of the railway would also permit easier rescue in the event a climb encountered accident or illness. However, sportsmen would no doubt claim that such a railway would devalue the effort of climbing, and no doubt the sight of unfit plebeians sipping hot chocolate from the observation deck as the frost-covered climbers staggered the last few hundred feet would take away the feeling of attainment.

<u>Applicability of VSL as a tool in mixed activities.</u> Such a railway would constitute an interesting anchoring problem. Today the public effectively accepts a high death rate among climbers, and in fact such literally climb over the bodies of those who tried and failed, given the difficulty of retrieving bodies or even burying them properly on the mountain. (23) A cog railway would place the safety expectations, at least for railway passengers, back in the realms of ordinary transportation expectations even though such a railway would still face a special set of risks (e.g. avalanches, failure of pressurization systems) that would normally not be present in rail travel. Would a death rate that was far lower than that of Everest climbers, but still significantly higher than that of railway passengers, be considered acceptable by the general public? How is an implied VSL to be assigned to each mode, and how could an aggregate VSL for all trips to the summit including both modes be determined? And would an aggregate VSL be meaningful in any way?

This, in effect, might be exactly the problem faced by suborbital flight providers, if it turns out that their passengers, over time, experience a death rate that is far lower than that of governmental space travelers to date, but still higher than ordinary air passengers. It would be entirely a matter of anchoring, as to which category the activity was mentally assigned.

Historically, the question of sightseeing flights over Antarctica might be a useful parallel. Between 1977 and 1978, Air New Zealand conducted day-long tourist flights over Antarctica. The flights did not land in Antarctica, but did fly well below ordinary operating altitudes in order to give passengers a good view of the land below. They used unmodified DC-10 airliners and regular crews from Air New. On 28 November 1978 one such flight suffered a navigational error and flew into the side of Mt. Erebus in Antarctica, killing all 258 people on board. (24)

Subsequently such flights were ended. The fact that the flights were operated by routine air transport equipment and crew functioning in a familiar manner strongly anchored public opinion to expect routine passenger aviation levels of safety. Expectations of Antarctic travel had changed from “safe return doubtful” to the same safety level as a commuter flight from Auckland to Wellington.

Returning to the question of meaningful VSLs, the above examples give some idea of the complexity of trying to arrive at meaningful VSLs for expeditionary modes that are used by different user types with quite different motivations. Given the example of a suborbital flight which is being flown by both a researcher in furtherance of his research, and a tourist in furtherance of his personal experience goals, is it meaningful to apply the same VSL for both, considering that the researcher may be making a tradeoff between a suborbital and an orbital flight, while the personal experience flight participant may be making a tradeoff between a suborbital flight and a BASE jump?

One potentially useful approach to VSL calculations with very low numbers and a mix of motivations of actors in the field was done by two researchers at Syracuse who studied the Everest route decision in the context of VSL calculation. (25) They dealt with the question of VSL in an area with mixed sporting and occupational motivations by studying the decisions of only the professional international guides who accompanied climbing expeditions, who climb as a profession. A parallel methodology for space might study suborbital flight participants but restrict the study to researchers who were flying as an adjunct to their professional research, rather than those who were paying out of pocket for the purpose of personal experience.

Therefore, the supporting research methodologies for civil regulation, such as Value of Statistical Life calculations, are of only limited value in sport/recreational regulation. (28)

In addition to the general problem of applying VSL methodologies intended for large numbers of users to activities with small overall numbers of participants, it is difficult to apply the metric of user preference pricing to participants who often incur additional costs to pursue a more dangerous method of carrying out an activity, in effect giving them a negative preference value.

It is useful to compare and contrast ordinary skydiving to BASE (“Bridge, Antenna, Span, and Earth”) jumping, as both involve the same technology and general procedures, but in which the latter form of parachuting (also including wingsuiting) is far more dangerous than even the more extreme forms of skydiving. (29) Also, skydiving is unambiguously under the authority of the FAA in the US, which has a well-developed regulatory approach, whereas BASE jumping is not systematically regulated either in the US or other countries, being regulated when at all primarily by landlord-tenant rules imposed by the owners of the structures from which BASE jumpers jump. For example, the US National Park Service has jurisdiction over many of the landmarks popular with BASE jumpers, and requires an event-specific permit to be negotiated for each jump. Many areas forbid jumping entirely, although this does not deter many from jumping illegally.

Extreme Mountaineering includes risk levels similar to those of experimental aviation or skydiving, but do not approach BASE jumping except for the most extreme examples, such as climbing mountains in the class of Mt. Everest. In general extreme mountaineering includes climbs requiring extensive use of technical equipment, and climbs requiring oxygen. Regulation is haphazard to nonexistent depending on country, and often is confined to inspection for adequate supplies and equipment, and on popular routes, permits intended to limit the number of climbers on the mountain at any given time. Everest, for example, is at saturation already and reduction of the total number of annual climbs is under consideration. Limiting numbers of climbers on the mountain at any given time is probably the only practical means of avoiding future casualty lists of the size of the 2015 avalanche.

Extreme diving is defined here as diving to unusual depths, in unusual environments (e.g., diving in bodies of water in caves), and/or using unusual technical solutions such as breathing gas mixes other than compressed air. Recreational diving in such categories is less common than such diving for military, occupational, or scientific research purposes, and equipment, techniques, training, and regulation all tend to follow standards set in such areas. As with other extreme non-aviation sports, there is no single or comprehensive regulatory regime for such activities. Our research has turned up no evidence that what regulation does exist uses any risk calculation specific to extreme recreational applications of the area of activity, rather, regulation tends to be adapted from occupational or other non-recreational regulatory uses.

Additionally, fatalities are often reported when aggregated in total fatality figures for broader categories of activity that are in general much safer. For example, although general aviation is statistically more dangerous that commercial aviation, the greatest number of fatalities is clustered into the categories of pilots with less than 500 hours of flight experience, and of those, pilots who fly into bad weather, a form of poor judgment also more typical of inexperienced pilots. Pilots with more than 500 hours of experience have almost as good a record as commercial pilots. Similarly, ordinary SCUBA diving to shallow depths is a quite safe activity similar to any swimming in safety; deep or other extreme diving can increase hazards, especially without proper training.

An example of extreme environment travel is Antarctic ship-borne tourist travel. By using cruise ships to transport tourists to Antarctic waters and house them while off the coast, it is possible to experience the Antarctic environment in reasonable comfort and safety with the option of day excursions to the continent with only minimal exposure to the actual hazards of Antarctic travel. Regulation is provided by the state of registry of the ship, plus international maritime law and certain additional restrictions, mainly environmental, added by the Antarctic Treaties. Insurance requirements also impose the limitations and special restrictions developed by the considerable experience of navigation in northern and Arctic waters. Thus there is little need for a specifically “Antarctic” law or regulatory system, since adaptation of ordinary legal areas is generally sufficient.

<u>Regulation of risks, liability issues and outcomes across sectors.</u> In the US, the great bulk of all activity subject to direct or indirect regulation for first- and third-party risk is regulated via the commercial and occupational power of the Federal, state, and local governments. This includes regulation under the Federal Government’s constitutional powers to regulate international and interstate commerce, and under state and local general police powers. Transportation, and particularly aviation, is regulated through a special common carrier regime that is particularly oriented toward reducing passenger risk in scheduled transport services.

Aviation as a Federal reservation, is under the sole and comprehensive authority of the FAA. (30) Other commercial activities are regulated primarily through occupational safety regimes primarily oriented toward reducing risk to employees, with general public (third-party) safety often primarily dealt with by local authorities under the police power, such as land-use regulation to segregate heavy industry from residential areas. Safety of scientific researchers is typically a special case of occupational safety.

Recreational safety in aviation is dealt with through subsets of general aviation regulation, which is generally less strict than commercial aviation, and relies more on assumed risk doctrines. Categories such as “light/sport aviation” exempt craft below certain weight limits from certification requirements, and the “experimental” category allows for a wide variety of home-built aircraft, so long as they are not used for commercial purposes. Fatality rates are substantially higher in the experimental category, almost by definition.

Recreational safety in other areas is dealt with by a patchwork of regulation often provided by landlord-tenant authority of recreation site (e.g., park rules) or contractual conditions of service vendors (e.g., rules of a Scuba equipment rental company). Rules are often adaptations of, or incorporation by reference of rules developed by occupational safety authorities (e.g., OSHA occupational rules, sometimes supplemented by empirically-derived situation-specific rules by local managers).

Despite the haphazard nature of the non-aviation rule approach, safety outcomes are roughly comparable between aviation and non-aviation activities. Small subsets of activity are highly hazardous (BASE jumping, experimental aircraft flight). A wider range of activities is somewhat more hazardous than everyday life, but reducible by experience-based rule sets and formal or informal systems for imparting lessons learned, and by learning from parallel experiences in comparable areas (e.g., adapting OSHA rules from commercial diving and military diving to hazardous research diving, but with commonsense adaptations, such as recognizing that research divers do not handle the heavy weights as do commercial divers.)

Hardly any research or recreational activities rely on systematic analytical tools such as VSL calculations specific to their subset of activities. If such tools were to be applied, they would require review and possible revision to account for substantial differences in the size of populations addressed, and in some cases, very different attitudes for risk and risk preferences.

V. Observations/conclusions.

1. Wide range of risks permitted and managed.

In the course of this research a wide range of activities was reviewed. Despite the general public perception of riskiness of many of these activities, the range of risk was actually quite wide. Many activities in areas considered hazardous, such as underwater diving, parachuting, non-commercial aviation, or mountaineering can be practiced at levels and in ways in which, provided proper equipment, techniques, and training are employed, risk can be reduced to levels comparable to or only slightly higher than those encountered in everyday life. Perceptions of risk are often higher than the reality because of anchoring of expectations through media exposure to the most extreme versions of the activity, or experiences in past years before improvements in materials and techniques became available. Conversely, some persons expose themselves to unneeded risk because they mistake a careful practice observing limitations and cautions for the sort of activity undertaken in everyday life with few if any special precautions. One of the most frequent causes of light-aircraft fatalities, for instance, comes from inexperienced pilots assuming that light aircraft can be flown safely in the same extremes of weather that are acceptable for automobile travel.

It would be a valid general conclusion that a wide range of risk is managed successfully by assumed-risk and informed-risk doctrines. Key to this management is applied experience, rapid feedback of lessons learned, and selective exclusion of the most hazardous practices, rather than blanket bans of general areas of activity. If analytical tools are used in deriving regulation, the quest for false precision should be avoided, and wide deference should be given to empirical knowledge and managerial experience. However, if a valid statistical tool can be developed for understanding comparable risk in different research activities, it might help avoid widely disparate decisions based on perceptions (rather than realities) of risk and risk tolerance in publicly funded research facilities in extreme environments, and therefore unnecessary under-utilization of highly expensive facilities.

2. No general social consensus of "acceptable risk".

The general public does not, as a rule, understand statistics, and to the extent they do, are often uninformed or unaware of changes in the riskiness of an activity due to technological progress or a successful risk-reduction program on the part of management, regulators, and other interested third parties such as insurers. Perceptions of the riskiness of air travel, for example, have been affected by memories of long-past accidents and media coverage thereof, whereas passenger deaths in scheduled US passenger aviation have declined dramatically in the past several decades. Estimates of risk are often at variance with reality by several orders of magnitude. We have discussed the great variance in risk acceptance between the US Antarctic and space programs, for example. The general public is even less able to make finer-grained distinctions within categories of activity, such as between general aviation using proven and reliable aircraft flown by experienced pilots and a homebuilt, experimental aircraft flown by a pilot with little experience. Similarly, basic skydiving from an aircraft with proper instruction, or shallow-water Scuba diving, again with proper equipment and instruction, are relatively low-risk adventure sports. Extreme diving, or BASE jumping, are both highly hazardous and can easily go wrong even for seasoned professionals using state-of-the-art equipment. Public agencies must take pains to communicate clearly the risks that may be borne in carrying out potentially hazardous missions to avoid either complacency or an unrealistic estimate of riskiness. It may be advantageous to create and maintain a uniform standard of acceptable risk for Federally-operated or Federally-supported research in hazardous environments in order to discourage unrealistic communications regarding risk from agency managers with incentives to do so. Locating the maintenance of such a standard in an independent entity within the Executive Branch may help insulate the standard keepers from agency pressures, and remove pressure on managers to communicate unrealistically.

3. Perceptions, categories, and anchoring important for public reaction to risk.

As discussed previously, the general innumeracy of the population leaves them liable to "anchoring" phenomena, particularly in areas such as space that are the subject of a wide range of media and popular culture influences. Media information about space ranges from well-researched, highly informative print media, television, and Web sources, including extensive NASA informational efforts, through sporadic and sometimes misleading event-driven reporting in general print and video media, though highly opinionated and frequently sensationalistic media and blogospheric coverage, some of which is inadvertently or deliberately spreading substantial misinformation. Yet other products verge into pure science fiction and items such as faked lunar landing conspiracy theories, saucer cult and alien abduction reports, which probably are more properly the province of psychology. Yet all of these help anchor public attitudes and expectations regarding space.

Tom Wolfe's book *The Right Stuff* effectively related the way in which changed context radically altered public perception of the risk incurred by the astronaut corps, which at the beginning of the US manned space program was drawn entirely from the existing pool of military test pilots. The military test pilot corps had been experiencing extraordinarily high loss rates for decades, as the rapid onset of progress in aviation continually presented them with entirely new technologies that were rushed into test articles and prototype versions with very little firm research, essentially testing to destruction on many if not most first flights. They earned only a modest supplement to ordinary flight pay and died with almost no public attention. When the context changed to the Space Race with the USSR, however, essentially similar risks were suddenly perceived as great heroism.

Anchoring also includes the effects of lagging perceptions, such as the acceptance of high hazards in the polar exploration sphere, even while luxury cruises to the Arctic and Antarctic are assumed to be carried out in perfect safety. Thus the risk of overwintering at the South Pole does not generate any demands for even mildly increased costs such as maintaining a backup physician at the station (essentially costing only the salary differential between an ordinary scientists and one cross-qualified as an MD). US space activity has been more affected by anchoring than most other areas of higher-risk research, given the very strong public attention focused on the field at its inception, and the absence of in-space fatal accidents in the US program, in contrast to several fatal accidents in the Soviet program. This helped lend an illusion, prior to the loss of *Challenger* and *Columbia*, that travel in the Space Shuttle had achieved something like airline levels of safety, which caused dissonance when the loses in flight, particularly of *Challenger,* occurred.

A countervailing tendency, also affecting anchoring, has been the widely-accepted narrative parallel between the exploration, and eventual settlement of space, with the settlement of North America and the hazards of pioneering. The ground for this parallel had already been prepared by a long period of anticipatory science fiction, in which the paradigm had been assumed even to the degree of anticipating native populations on other planets. A major part of the American settlement narrative has been the hazards of pioneering, which were real enough, and the fortitude of the pioneering populations. It is likely that this narrative has been a factor in the persistent response in polling, subsequent to each fatal accident in space, that the exploration of space was worth the cost in lives (reference polling data matrix). A non-representative but random sample of quotes in media articles summarizing polling data indicates that the pioneering parallel was frequently referenced, along with substantial numbers of references to the frequent deaths in pioneering aviation, and less frequently polar exploration.

It is worth considering to what extent a uniform federal standard of risk in higher-risk research activities could affect public attitude anchoring, by making the general public more aware of overall fatalities in research-related activities. One step might be to create a high-profile civic honor for researchers and research-related support personnel who have died or suffered severe injury in the course of their research, undertaken for the advancement of human knowledge and capabilities. This might take the form of a medal, presented posthumously in the case of death, and perhaps a dedicated area in a National Cemetery, or a special cemetery, for those who have died in such causes. This would both more visibly and distinctly honor those who have given lives in space, and help place those fatalities in perspective, in a visible and conspicuous manner, by placing them side by side with those who have died in similar causes.

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